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Nomura et al.

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[45] Date of Patent: Feb. 16, 1999

[54] **ANESTHETIC DEPTH MEASURING APPARATUS**

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[73] Assignee: **Colin Corporation**, Aichi, Japan

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[86] PCT No.: **PCT/JP96/01418**

§ 371 Date: **Jan. 27, 1997**

§ 102(e) Date: **Jan. 27, 1997**

[87] PCT Pub. No.: **WO96/38087**

PCT Pub. Date: **Dec. 5, 1996**

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Jun. 2, 1995 [JP] Japan 7-136948
Jun. 2, 1995 [JP] Japan 7-136949

[51] **Int. Cl.**[6] **A61B 5/00**

[52] **U.S. Cl.** **600/485**; 600/500

[58] **Field of Search** 600/485, 493–6, 600/500, 748

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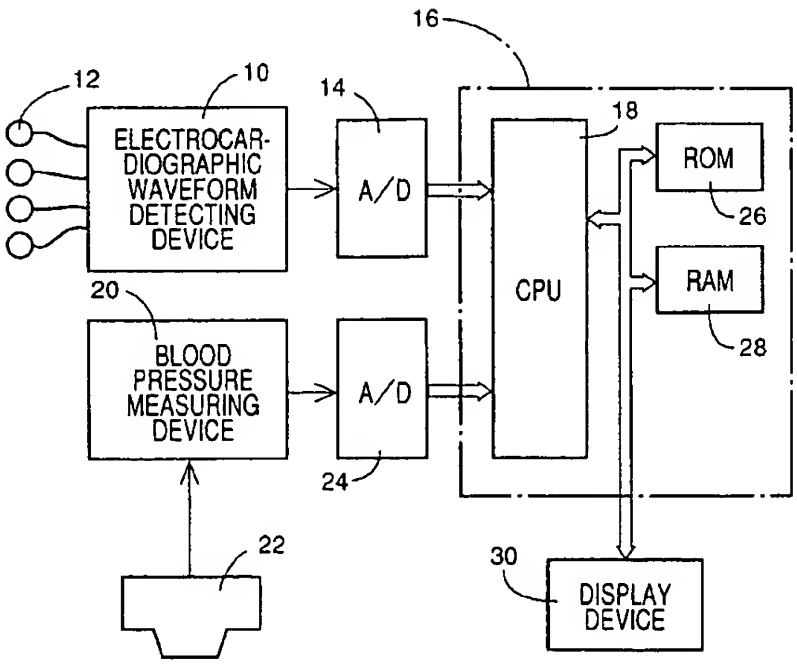
Primary Examiner—Robert L. Nasser
Attorney, Agent, or Firm—Oliff & Berridge, PLC

[57] **ABSTRACT**

From a fluctuation of pulse periods of a subject continuously measured by a pulse period measuring device, a first pulse period fluctuation signal HFC_{RR} which corresponds to a first pulse period fluctuation component produced in substantial synchronism with a respiration of the subject and a second pulse period fluctuation signal LFC_{RR} which corresponds to a second pulse period fluctuation component having a predetermined frequency lower than a frequency of the first pulse period fluctuation component are extracted by a pulse period fluctuation signal extracting means. Then, based on a ratio (HFC_{RR}/LFC_{RR}) of the first pulse period fluctuation signal HFC_{RR} to the second pulse period fluctuation signal LFC_{RR}, an anesthetic depth of the subject is calculated by an anesthetic depth calculating means. Thus, the present apparatus can objectively or quantitatively calculate the anesthetic depth of the subject. Additionally, the apparatus can accurately measure the anesthetic depth of the subject without needing operator's skill or the like.

4 Claims, 13 Drawing Sheets



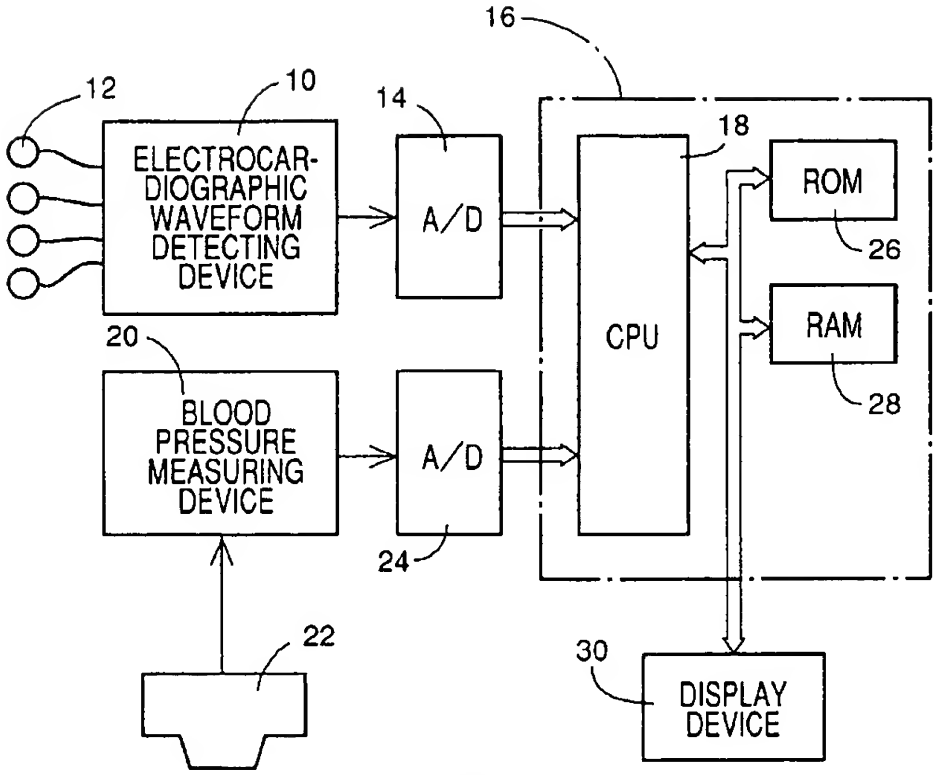

16
12
10
14
18
ELECTROCAR-
DIOGRAPHIC
WAVEFORM
DETECTING
DEVICE
A/D
ROM
26
CPU
RAM
28
20
BLOOD
PRESSURE
MEASURING
DEVICE
A/D
24
22
30
DISPLAY
DEVICE

FIG. 1

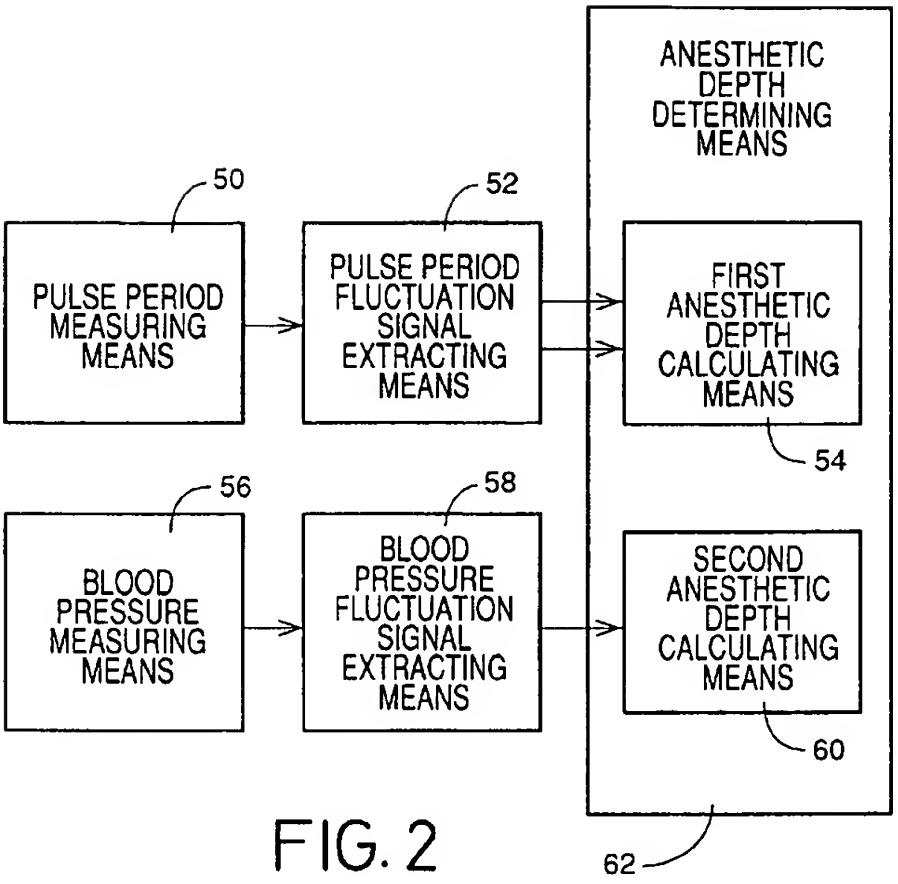

ANESTHETIC DEPTH DETERMINING MEANS
50
PULSE PERIOD MEASURING MEANS
52
PULSE PERIOD FLUCTUATION SIGNAL EXTRACTING MEANS
FIRST ANESTHETIC DEPTH CALCULATING MEANS
54
56
BLOOD PRESSURE MEASURING MEANS
58
BLOOD PRESSURE FLUCTUATION SIGNAL EXTRACTING MEANS
SECOND ANESTHETIC DEPTH CALCULATING MEANS
60
62

FIG. 2

FIG. 3

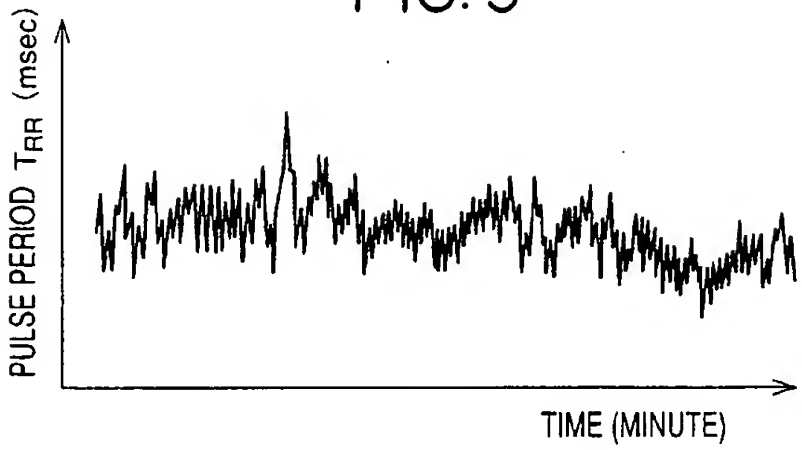

PULSE PERIOD T_{RR} (msec)
TIME (MINUTE)

FIG. 4

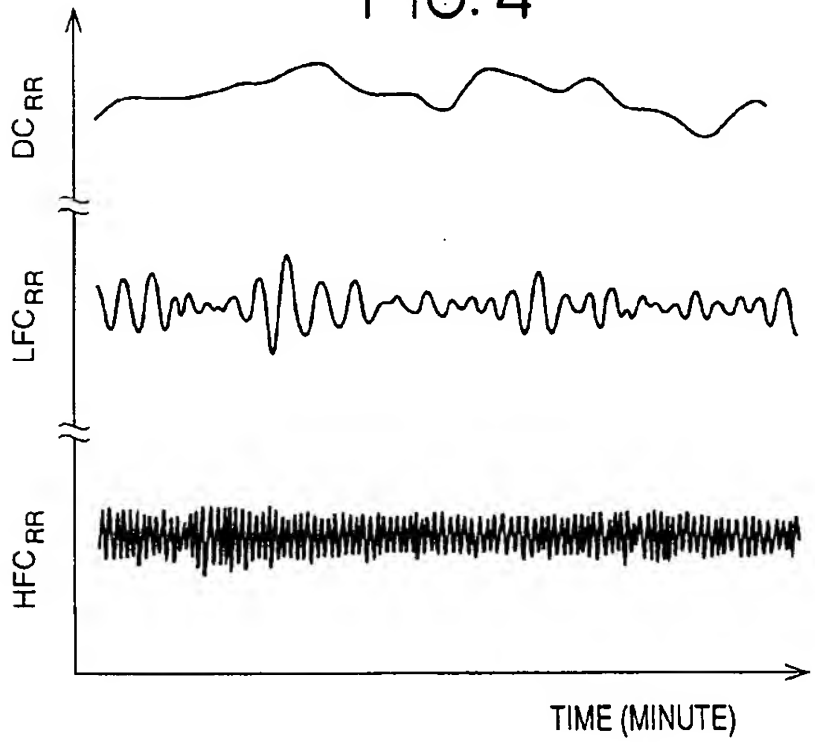

DC_{RR}
LFC_{RR}
HFC_{RR}
TIME (MINUTE)

FIG. 5

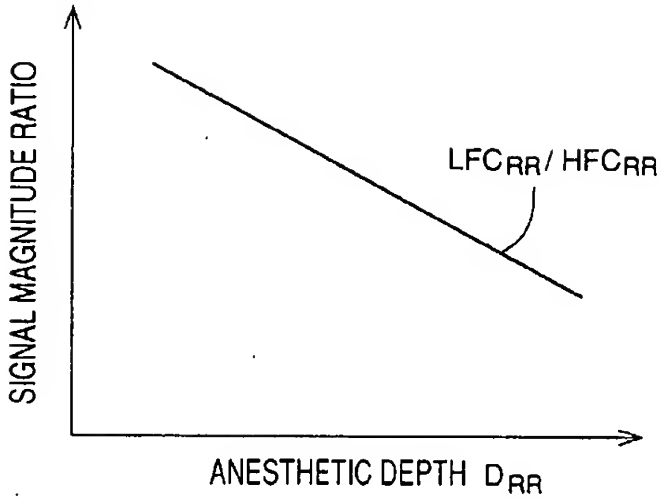

SIGNAL MAGNITUDE RATIO
LFC$_{RR}$/ HFC$_{RR}$
ANESTHETIC DEPTH D$_{RR}$

FIG. 6

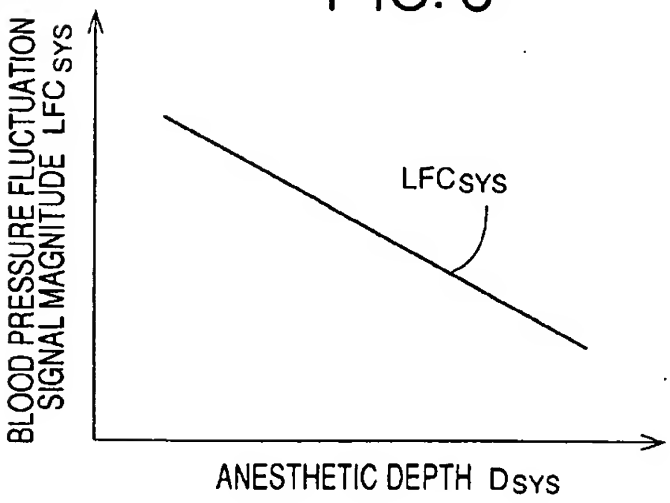
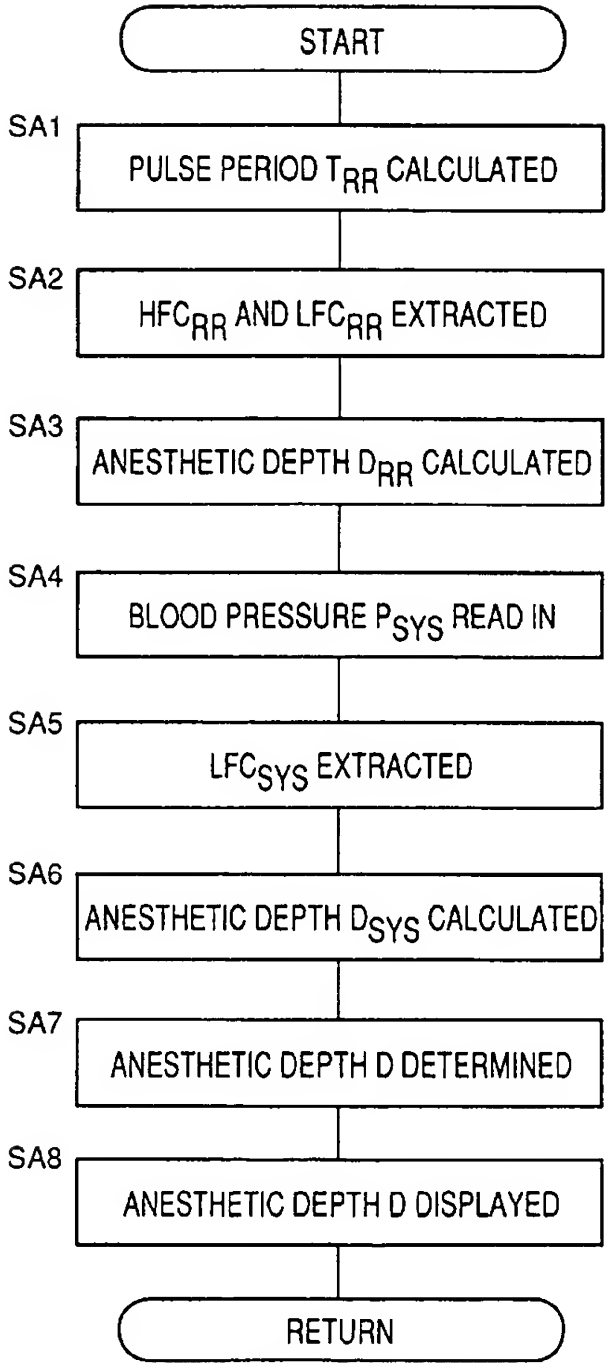

BLOOD PRESSURE FLUCTUATION SIGNAL MAGNITUDE LFC SYS
LFC$_{SYS}$
ANESTHETIC DEPTH D$_{SYS}$

FIG. 7


START
SA1
PULSE PERIOD T_{RR} CALCULATED
SA2
HFC_{RR} AND LFC_{RR} EXTRACTED
SA3
ANESTHETIC DEPTH D_{RR} CALCULATED
SA4
BLOOD PRESSURE P_{SYS} READ IN
SA5
LFC_{SYS} EXTRACTED
SA6
ANESTHETIC DEPTH D_{SYS} CALCULATED
SA7
ANESTHETIC DEPTH D DETERMINED
SA8
ANESTHETIC DEPTH D DISPLAYED
RETURN

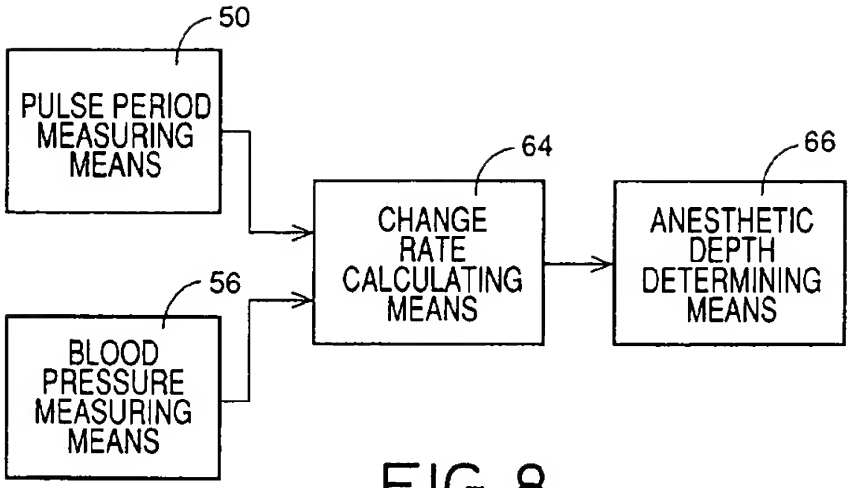

50
PULSE PERIOD MEASURING MEANS
64
CHANGE RATE CALCULATING MEANS
66
ANESTHETIC DEPTH DETERMINING MEANS
56
BLOOD PRESSURE MEASURING MEANS

FIG. 8

FIG. 9

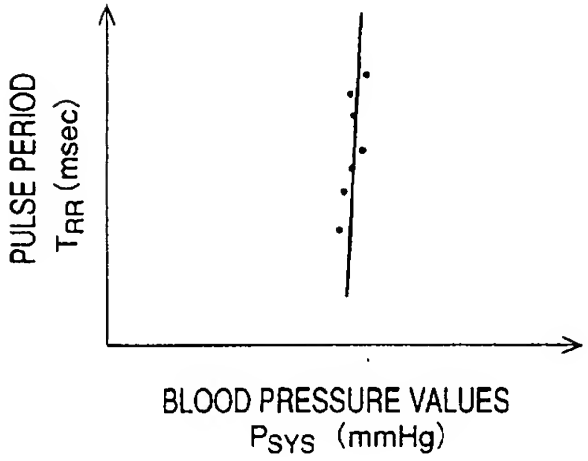

PULSE PERIOD
T_{RR} (msec)
BLOOD PRESSURE VALUES
P_{SYS} (mmHg)

FIG. 10

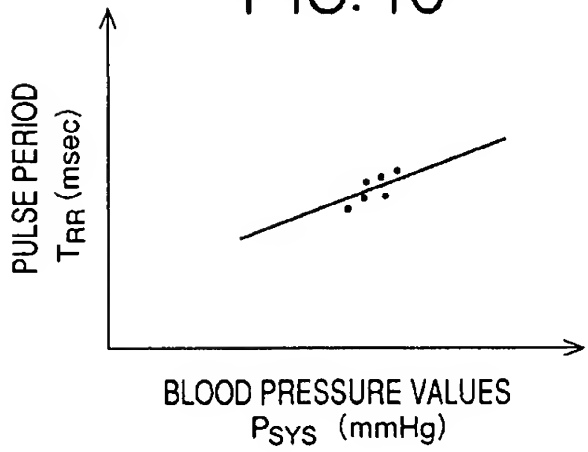

PULSE PERIOD
T_{RR} (msec)
BLOOD PRESSURE VALUES
P_{SYS} (mmHg)

FIG. 11

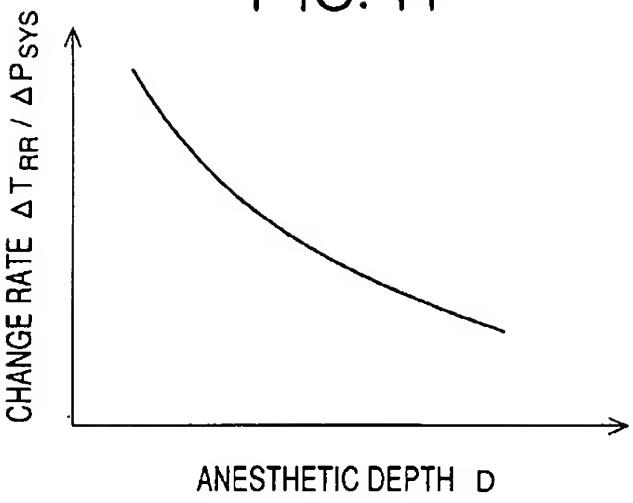
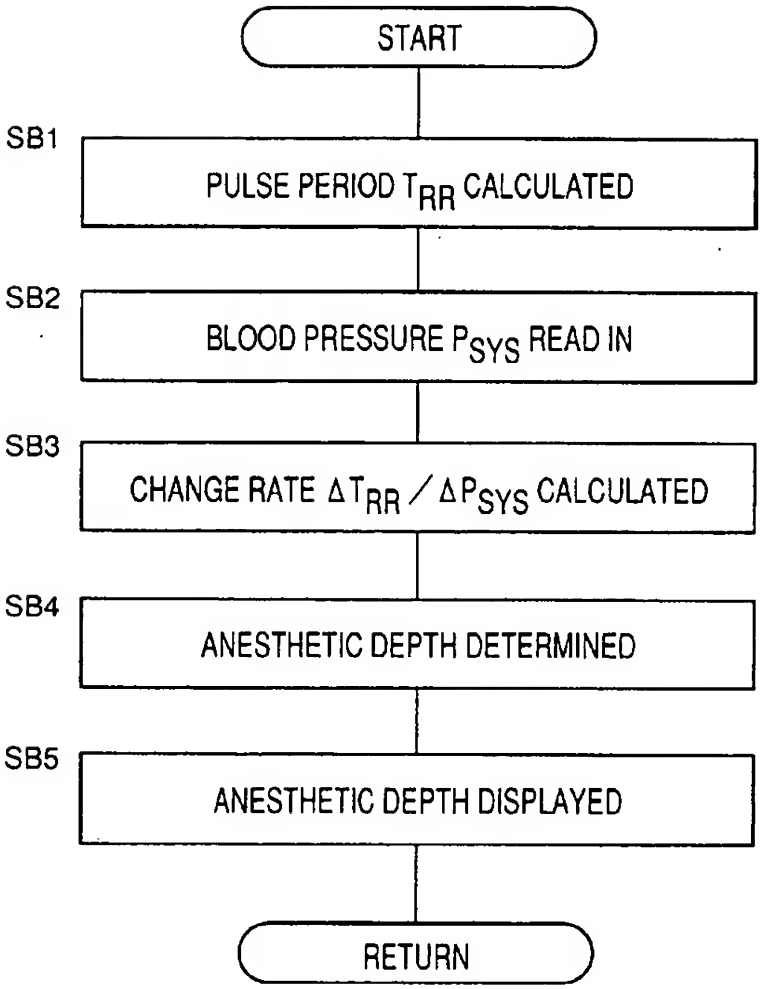


FIG. 12


START
SB1
PULSE PERIOD T_{RR} CALCULATED
SB2
BLOOD PRESSURE P_{SYS} READ IN
SB3
CHANGE RATE $\Delta T_{RR} / \Delta P_{SYS}$ CALCULATED
SB4
ANESTHETIC DEPTH DETERMINED
SB5
ANESTHETIC DEPTH DISPLAYED
RETURN

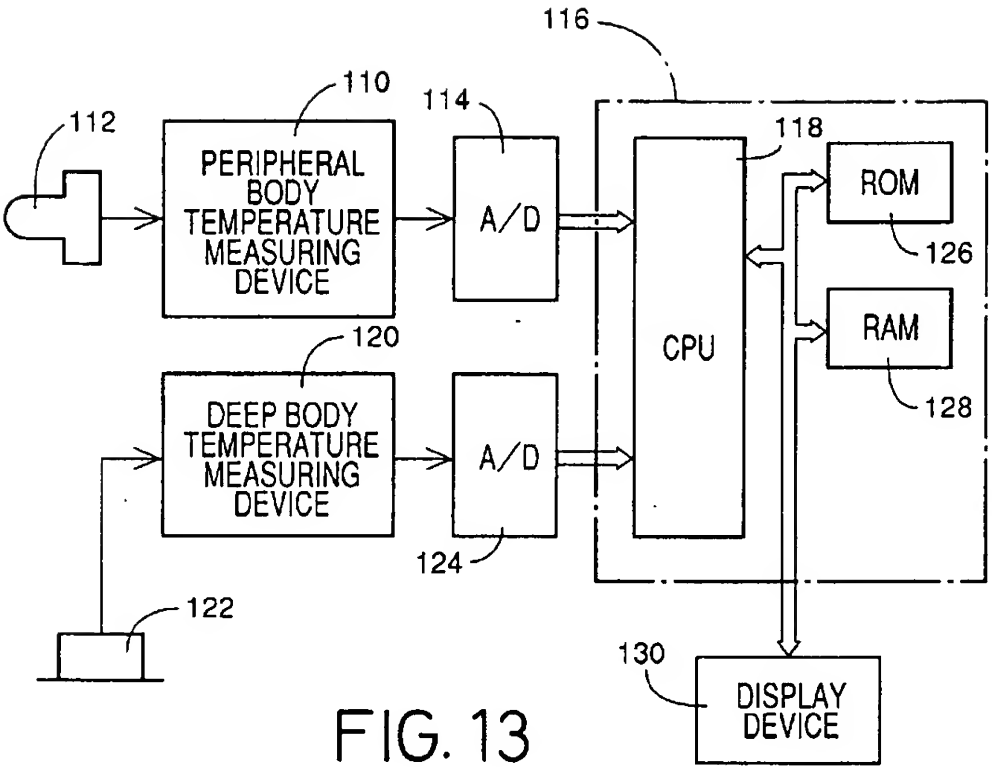

116
110
114
112
118
PERIPHERAL BODY TEMPERATURE MEASURING DEVICE
A/D
ROM
126
CPU
RAM
120
128
DEEP BODY TEMPERATURE MEASURING DEVICE
A/D
124
122
130
DISPLAY DEVICE

FIG. 13

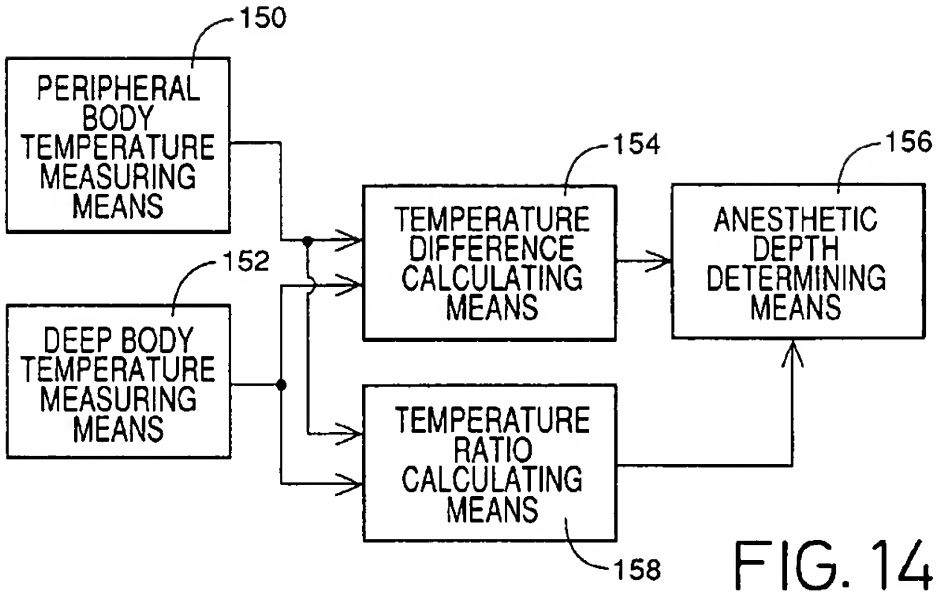

150
PERIPHERAL BODY TEMPERATURE MEASURING MEANS
152
DEEP BODY TEMPERATURE MEASURING MEANS
154
TEMPERATURE DIFFERENCE CALCULATING MEANS
156
ANESTHETIC DEPTH DETERMINING MEANS
TEMPERATURE RATIO CALCULATING MEANS
158

FIG. 14

FIG. 15

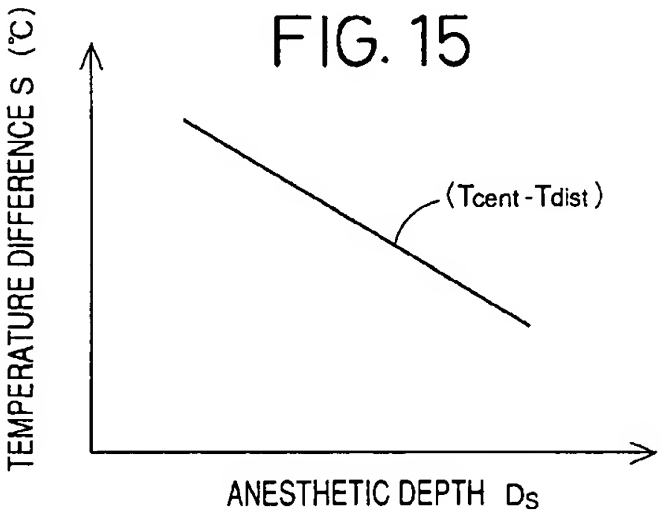

TEMPERATURE DIFFERENCE S (°C)
(Tcent - Tdist)
ANESTHETIC DEPTH Ds

FIG. 16

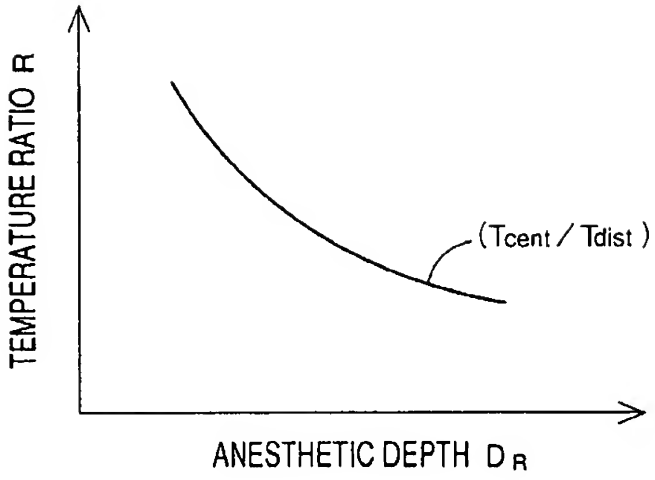
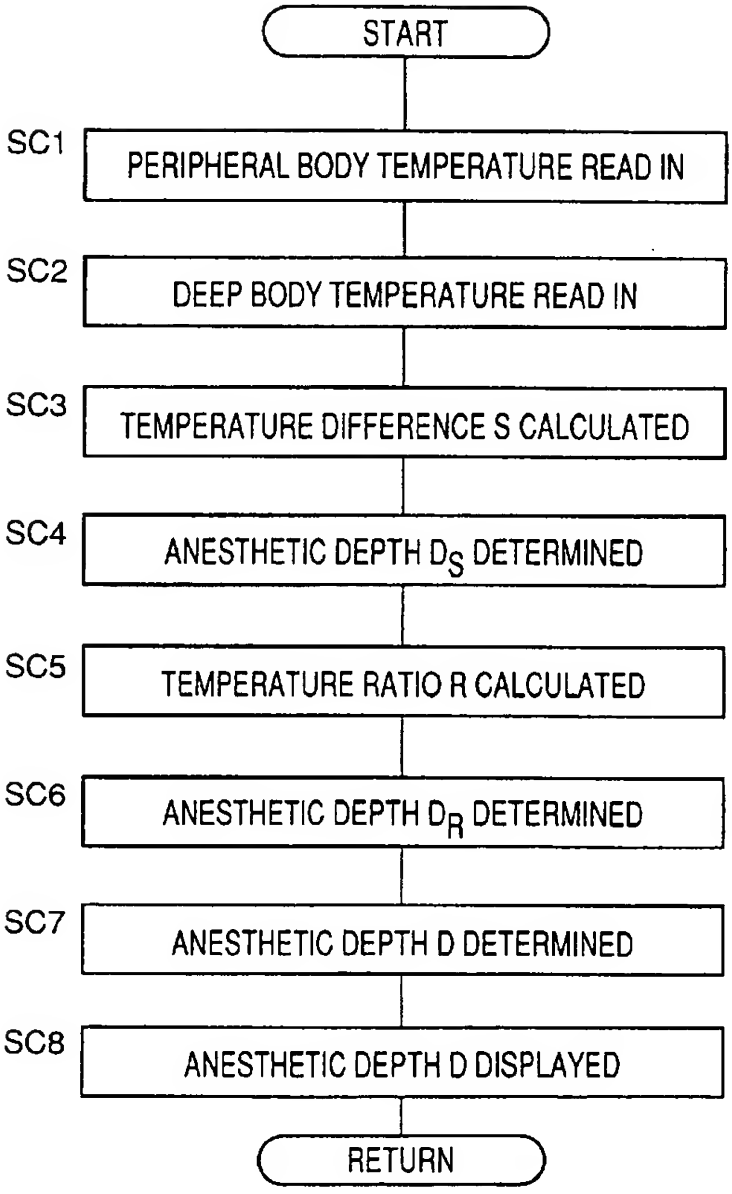


FIG. 17


START
SC1
PERIPHERAL BODY TEMPERATURE READ IN
SC2
DEEP BODY TEMPERATURE READ IN
SC3
TEMPERATURE DIFFERENCE S CALCULATED
SC4
ANESTHETIC DEPTH D_S DETERMINED
SC5
TEMPERATURE RATIO R CALCULATED
SC6
ANESTHETIC DEPTH D_R DETERMINED
SC7
ANESTHETIC DEPTH D DETERMINED
SC8
ANESTHETIC DEPTH D DISPLAYED
RETURN

ANESTHETIC DEPTH MEASURING APPARATUS

FIELD OF THE ART

The present invention relates to an anesthetic depth measuring apparatus for measuring an anesthetic depth of a living subject.

BACKGROUND OF THE INVENTION

When a patient is anesthetized for a surgery or the like, it is required to maintain a suitable anesthetic depth so as to protect the patient from stress or pain due to the surgery. Conventionally, for example, an anesthetic depth has been subjectively or empirically recognized by monitoring a change of a blood pressure, a heart rate or a respiration rate of the patient, resulting from a stimulation of the surgery, or observing a reflex of eyelashes, a dimension of a pupil, a hue of a limb or a body temperature of the patient.

However, since the anesthetic depth recognition based on the change of the blood pressure, the heart rate or the respiration rate, or based on the reflex of the eyelashes, the dimension of the pupil, the hue of the limb or the body temperature is performed depending on a subjective judgement of anesthetists or the like, the anesthetists are required to have a long-time experience and a skill. In addition, it is not easy to objectively or accurately recognize the anesthetic depth. It is therefore an object of the present invention to provide an anesthetic depth measuring apparatus for objectively measuring an anesthetic depth of a living subject.

The inventors of the present invention have continued their study in the background of the above described situation, and they have found that a magnitude of a pulse period fluctuation component produced in synchronism with a respiration of a subject, a magnitude of a blood pressure fluctuation component having a frequency lower than a frequency of the respiration of the subject or a rate of change of the pulse period to the blood pressure of the subject has a close relation to an activity level of subject's parasympathetic nerve or sympathetic nerve, whereby an anesthetic depth of the subject can be objectively measured on the basis of the magnitude of the above mentioned fluctuation component, when the subject is anesthetized.

Moreover, the present inventors have found that the influences of the anesthesia on a peripheral body temperature and a deep body temperature are different from each other, and a difference between the peripheral body temperature and the deep body temperature has a close relation to an activity level of a nerve of the subject, whereby an anesthetic depth of the subject can be objectively measured on the basis of the difference. The present invention has been developed based on those findings.

DISCLOSURE OF THE INVENTION

The above object may be achieved according to the first invention which provides an anesthetic depth measuring apparatus for measuring an anesthetic depth of a living subject, characterized by comprising: (a) a pulse period measuring device which continuously measures a period of a pulse of the subject; (b) pulse period fluctuation signal extracting means for extracting, from a fluctuation of the pulse periods continuously measured by the pulse period measuring device, a first pulse period fluctuation signal which corresponds to a first pulse period fluctuation component produced in substantial synchronism with a respiration of the subject and a second pulse period fluctuation signal which corresponds to a second pulse period fluctuation component having a predetermined frequency lower than a frequency of the first pulse period fluctuation component; and (c) anesthetic depth calculating means for calculating an anesthetic depth of the subject based on a ratio of the first pulse period fluctuation signal to the second pulse period fluctuation signal.

In the above mentioned apparatus, from a fluctuation of the pulse periods continuously measured by the pulse period measuring device, the first pulse period fluctuation signal which corresponds to the first pulse period fluctuation component produced in substantial synchronism with the respiration of the subject and the second pulse period fluctuation signal which corresponds to the second pulse period fluctuation component having a predetermined frequency lower than a frequency of the first pulse period fluctuation component are extracted by the pulse period fluctuation signal extracting means. Then, based on a ratio of the first pulse period fluctuation signal to the second pulse period fluctuation signal, the anesthetic depth of the subject is calculated by the anesthetic depth calculating means. Thus, the present apparatus can objectively or quantitatively calculate the anesthetic depth of the subject. Additionally, the apparatus can accurately measure the anesthetic depth without needing operator's skill or the like.

The above object may be achieved according to the second invention which provides an anesthetic depth measuring apparatus for measuring an anesthetic depth of a living subject, characterized by comprising: (a) a blood pressure measuring device which continuously measures a blood pressure value of the subject; (b) blood pressure fluctuation signal extracting means for extracting, from a fluctuation of the blood pressure values continuously measured by the blood pressure measuring device, a blood pressure fluctuation signal which corresponds to a blood pressure fluctuation component having a predetermined frequency lower than a frequency of a respiration of the subject; and (c) anesthetic depth calculating means for calculating an anesthetic depth of the subject based on a magnitude of the blood pressure fluctuation signal.

In the above mentioned apparatus, the blood pressure value of the subject is continuously measured by the blood pressure measuring device, and, from a fluctuation of the continuously measured blood pressure values, the blood pressure fluctuation signal which corresponds to the blood pressure fluctuation component having a predetermined frequency lower than a frequency of the respiration of the subject is extracted by the blood pressure fluctuation signal extracting means. Then, based on a magnitude of the blood pressure fluctuation signal, the anesthetic depth of the subject is calculated by the anesthetic depth calculating means. Thus, the present apparatus can objectively or quantitatively calculate the anesthetic depth of the subject. Additionally, the apparatus can accurately measure the anesthetic depth without needing operator's skill or the like.

The above object may be achieved according to the third invention which provides an anesthetic depth measuring apparatus for measuring an anesthetic depth of a living subject, characterized by comprising: (a) a pulse period measuring device which continuously measures a period of a pulse of the subject; (b) a blood pressure measuring device which continuously measures a blood pressure value of the subject; (c) change rate calculating means for calculating a rate of change of one of the blood pressure values continuously measured by the blood pressure measuring device and the pulse periods continuously measured by the pulse period measuring device, to the other of the blood pressure values

and the pulse periods; and (d) anesthetic depth determining means for determining an anesthetic depth of the subject based on the rate of change calculated by the change rate calculating means.

In the above mentioned apparatus, the pulse period of the subject is continuously measured by the pulse period measuring device, the blood pressure value of the subject is continuously measured by the blood pressure measuring device, and a rate of change of one of the blood pressure values and the pulse periods to the other of the blood pressure values and the pulse periods is calculated by the change rate calculating means. Then, based on the rate of change, the anesthetic depth of the subject is determined by the anesthetic depth determining means. Thus, the present apparatus can objectively or quantitatively determine the anesthetic depth of the subject. Additionally, the apparatus can accurately measure the anesthetic depth without needing operator's skill or the like.

The above object may be achieved according to the fourth invention which provides an anesthetic depth measuring apparatus for measuring an anesthetic depth of a living subject, characterized by comprising: (a) a peripheral body temperature measuring device which measures a peripheral body temperature of the subject; (b) a deep body temperature measuring device which measures a deep body temperature of the subject; (c) temperature difference calculating means for calculating a difference between the peripheral body temperature measured by the peripheral body temperature measuring device and the deep body temperature measured by the deep body temperature measuring device; and (d) anesthetic depth determining means for determining an anesthetic depth of the subject based on the difference calculated by the temperature difference calculating means.

In the above mentioned apparatus, the difference between the peripheral body temperature measured by the peripheral body temperature measuring device and the deep body temperature measured by the deep body temperature measuring device is calculated by the temperature difference calculating means. Then, based on the difference calculated by the temperature difference calculating means, the anesthetic depth of the subject is determined by the anesthetic depth determining means. Thus, the present apparatus can objectively or quantitatively determine the anesthetic depth of the subject. Additionally, the apparatus can accurately calculate the anesthetic depth without needing operator's skill or the like.

The above object may be achieved according to the fifth invention which provides an anesthetic depth measuring apparatus for measuring an anesthetic depth of a living subject, characterized by comprising: (a) a peripheral body temperature measuring device which measures a peripheral body temperature of the subject; (b) a deep body temperature measuring device which measures a deep body temperature of the subject; (c) temperature ratio calculating means for calculating a ratio of the peripheral body temperature measured by the peripheral body temperature measuring device to the deep body temperature measured by the deep body temperature measuring device; and (d) anesthetic depth determining means for determining an anesthetic depth of the subject based on the ratio calculated by the temperature ratio calculating means.

In the above mentioned apparatus, the ratio of the peripheral body temperature measured by the peripheral body temperature measuring device to the deep body temperature measured by the deep body temperature measuring device is calculated by the temperature ratio calculating means. Then, based on the ratio calculated by the temperature ratio calculating means, the anesthetic depth of the subject is determined by the anesthetic depth determining means. Thus, the present apparatus can objectively or quantitatively determine the anesthetic depth of the subject. Additionally, the apparatus can accurately measure the anesthetic depth without needing operator's skill or the like.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a diagrammatic view for illustrating the construction of an anesthetic depth measuring apparatus embodying the present invention.

FIG. **2** is a block diagram for explaining various functions of a control device of the apparatus of FIG. **1**.

FIG. **3** is a view for illustrating a fluctuation of pulse periods T_{RR} measured by the apparatus of FIG. **1**.

FIG. **4** is a view for illustrating a first pulse period fluctuation signal HFC_{RR}, a second pulse period fluctuation signal LFC_{RR} and a pulse period direct current component DC_{RR} which are extracted from the fluctuation of the pulse periods T_{RR} measured by the apparatus of FIG. **1**.

FIG. **5** is a graph showing a relationship used by the apparatus of FIG. **1** for calculating an anesthetic depth D_{RR}.

FIG. **6** is a graph showing a relationship used by the apparatus of FIG. **1** for calculating an anesthetic depth D_{SYS}.

FIG. **7** is a flow chart representing the operation of the control device of the apparatus of FIG. **1**.

FIG. **8** is a block diagram corresponding to FIG. **2**, for explaining various functions of a control device of an anesthetic depth measuring apparatus as another embodiment according to the present invention.

FIG. **9** is a graph showing a relationship between pulse periods T_{RR} and blood pressure values P_{SYS} of a non-anesthetized subject.

FIG. **10** is a graph showing a relationship between pulse periods T_{RR} and blood pressure values P_{SYS} of an anesthetized subject.

FIG. **11** is a graph showing a relationship used by the apparatus of FIG. **8** for determining an anesthetic depth D based on a rate of change $\Delta T_{RR}/\Delta P_{SYS}$.

FIG. **12** is a flow chart representing the operation of the control device of the apparatus of FIG. **8**.

FIG. **13** is a diagrammatic view for illustrating the construction of an anesthetic depth measuring apparatus as yet another embodiment according to the present invention.

FIG. **14** is a block diagram for explaining various functions of a control device of the apparatus of FIG. **13**.

FIG. **15** is a graph showing a relationship used by the apparatus of FIG. **13** for determining an anesthetic depth D_S based on a temperature difference S ($=T_{cent}-T_{dist}$).

FIG. **16** is a graph showing a relationship used by the apparatus of FIG. **13** for determining an anesthetic depth D_R based on a temperature ratio R ($=T_{cent}/T_{dist}$).

FIG. **17** is a flow chart representing the operation of the control device of the apparatus of FIG. **13**.

THE BEST MODE FOR CARRYING OUT THE INVENTION

There will be described in detail an embodiment of the present invention, referring to the drawings.

FIG. **1** is a diagrammatic view for illustrating the construction of an anesthetic depth measuring apparatus

embodying the present invention. In the figure, an electrocardiographic waveform detecting device **10** includes a plurality of electrodes **12** which are put on a living subject. The device **10** continuously supplies a well-known electrocardiographic waveform signal successively produced in synchronism with a heartbeat of the subject who is generally anesthetized by an inhalation anesthetic, such as isoflurane, to a CPU **18** of a control device **16** via an A/D converter **14**.

A blood pressure measuring device **20** includes a pressure pulse wave detecting probe **22** adapted to be pressed, with a band (not shown), to an artery of the subject, such as a carotid artery, a radial artery or a pedal dorsal artery. The device **20** continuously measures a blood pressure value of the generally anesthetized subject based on each one pulse of the detected pulse wave and supplies a blood pressure signal representative of the blood pressure value to the CPU **18** of the control device **16** via an A/D converter **24**. This blood pressure measuring device **20** is constructed similarly to the blood pressure monitoring apparatus disclosed in U.S. Pat. No. 4,423,738 or laid-open publication No. 5-253196 of unexamined Japanese Patent Application.

The control device **16** is provided by a so-called microcomputer including the CPU **18**, a ROM **26** and a RAM **28**. The CPU **18** processes input signals, that is, the electrocardiographic waveform signal and the blood pressure signal, according to control programs pre-stored in the ROM **26** by utilizing a temporary-storage function of the RAM **28**, and controls a display device **30** so as to display an anesthetic depth D of the subject.

FIG. **2** is a block diagram for explaining various functions of the control device **16**. In the figure, a pulse period measuring means **50** measures a pulse period from a heartbeat synchronous wave, such as an electrocardiographic waveform, a pulse wave produced from an artery, or the like, produced in synchronism with a heartbeat of the subject. Preferably, by calculating a time interval between each pair of successive two pulses of the electrocardiographic waveform, for example, R-waves of the successive two pulses, the pulse period measuring means **50** continuously measures a pulse period T_{RR} of the anesthetized subject. The thus measured pulse periods T_{RR} have a fluctuation as shown in FIG. **3**, for example.

A pulse period fluctuation signal extracting means **52** extracts, from the fluctuation of the pulse periods T_{RR} continuously measured by the pulse period measuring means **50**, a first pulse period fluctuation signal HFC_{RR} which corresponds to a first pulse period fluctuation component produced in substantial synchronism with a respiration of the subject and a second pulse period fluctuation signal LFC_{RR} which corresponds to a second pulse period fluctuation component having a predetermined frequency lower than a frequency of the first pulse period fluctuation component. The pulse period fluctuation signal extracting means **52** performs a frequency analysis of the fluctuation of the pulse periods T_{RR}, with a fast Fourier transformation (FFT) method, an autoregression (AR) method, or the like. Then, the pulse period fluctuation signal extracting means **52** outputs, as the first and second pulse period fluctuation signals HFC_{RR}, LFC_{RR}, a magnitude (power) of a signal component having a frequency in the neighborhood of the frequency of the respiration of the subject and a magnitude (power) of a signal component having a frequency in the neighborhood of one third to one fourth of the frequency of the respiration of the subject, respectively. Specifically, the pulse period fluctuation signal extracting means **52** outputs, as the first and second pulse period fluctuation signals HFC_{RR}, LFC_{RR}, a magnitude of a signal component having a peak frequency in a predetermined frequency range including a frequency (e.g., 0.25 Hz) of the respiration of the subject and a magnitude of a signal component having a peak frequency in a predetermined frequency range including a frequency (e.g., 0.07 Hz) of about one third to one fourth of the frequency of the respiration of the subject, respectively. FIG. **4** respectively illustrates respective magnitudes of the first and second pulse period fluctuation signals HFC_{RR}, LFC_{RR} and a 0 Hz frequency component (direct current component) signal DC_{RR} which are extracted from the fluctuation of the pulse periods T_{RR}.

A first anesthetic depth calculating means **54** included in an anesthetic depth determining means **62** calculates a first anesthetic depth D_{RR} of the subject based on a ratio (LFC_{RR}/HFC_{RR}) of the first pulse period fluctuation signal HFC_{RR} to the second pulse period fluctuation signal LFC_{RR} which are extracted by the pulse period fluctuation signal extracting means **52**. The first anesthetic depth calculating means **54** calculates the first anesthetic depth D_{RR} based on the actual ratio (LFC_{RR}/HFC_{RR}) according to a pre-stored relationship shown in FIG. **5**, for example.

It is speculated that, in the action of a cardiac vagus nerve that is an efferent nerve originating from a circulatory center, a respiratory fluctuation occurs due to the interference of a respiratory center with the circulatory center at the level of a brain stem and a respiratory fluctuation of afferent signals produced from cardio-pulmonary receptors. Therefore, a fluctuation appearing in a frequency of ignition of a sino-auricular node can be regarded as a magnitude (power) of a signal component having a peak frequency in a frequency range including a frequency (e.g., 0.25 Hz) of the respiration of the subject, that is, the first pulse period fluctuation signal HFC_{RR}. Moreover, the respiratory fluctuation occurs to the action of a sympathetic nerve which controls the sino-auricular node. However, since the pulse rate control under the sympathetic nerve has a characteristic as a low frequency range filter, the sympathetic nerve can transmit only pulse rate fluctuations having extremely low frequencies, e.g., frequencies not higher than 0.15 Hz, and HFC_{RR} having an ordinary respiration frequency is exclusively mediated by the vagus nerve. Thus, the amplitude of HFC_{RR}, that is, magnitude of HFC_{RR} is in proportion to the activity of the cardiac vagus nerve and may be used as a useful and quantitative index of the cardiac vagus nerve activity. Meanwhile, it is speculated that the second pulse period fluctuation signal LFC_{RR} corresponding to a fluctuation component having a frequency of about one third to one fourth of a frequency of the first pulse period fluctuation signal HFC_{RR} is caused by a pulse rate fluctuation which occurs via a baroreceptor reflex mechanism. Afferent and efferent nerves of the reflex are an aortic sinus nerve, and cardiac parasympathetic and sympathetic nerves, respectively. Since the signal LFC_{RR} is in proportion to a product of the amplitude of the blood pressure and the sensitivity of the baroreceptors, the sympathetic nerve activity cannot be evaluated, if the baroreceptor reflex sensitivity is not constant. Thus, the ratio (LFC_{RR}/HFC_{RR}) closely corresponds to the nerve activity, because of being freed from an influence of an individual difference. The relationship shown in FIG. **5** is experimentally obtained in advance, based on the above described facts.

A blood pressure measuring means **56** which is provided by, for example, the blood pressure measuring device **20**, continuously measures a blood pressure value of the subject. A blood pressure fluctuation signal extracting means **58** extracts, from a fluctuation of the blood pressure values, for example, systolic blood pressure values P_{SYS}, continuously

measured by the blood pressure measuring means **56**, a blood pressure fluctuation signal LFC_{SYS} which corresponds to a blood pressure fluctuation component having a predetermined frequency lower than the frequency of the respiration of the subject. The blood pressure fluctuation signal extracting means **58** performs a frequency analysis of the fluctuation of the blood pressure values P_{SYS}, with a fast Fourier transformation (FFT) method, an autoregression (AR) method, or the like, and outputs, as the blood pressure fluctuation signal LFC_{SYS}, a magnitude (power) of a signal component having a peak frequency in a frequency range including a frequency (e.g., 0.07 Hz) of about one third to one fourth of the frequency of the respiration of the subject.

A second anesthetic depth calculating means **60** included in the anesthetic depth determining means **62** calculates a second anesthetic depth D_{SYS} of the subject based on a magnitude of the blood pressure fluctuation signal LFC_{SYS} according to a pre-stored relationship as shown in FIG. **6**, for example. Since it is speculated that the blood pressure fluctuation signal LFC_{SYS} representative of the fluctuation of blood pressure values results from a delay of a sympathetic vasomotor regulation system, an amplitude (magnitude) of the signal LFC_{SYS} may be used as a quantitative index of a vasomotor sympathetic nerve activity. A relationship shown in FIG. **6** is experimentally obtained in advance, based on the above described facts.

The anesthetic depth determining means **62** determines a third anesthetic depth D based on the first anesthetic depth D_{RR} calculated by the first anesthetic depth calculating means **54** and the second anesthetic depth D_{SYS} calculated by the second anesthetic depth calculating means **60**. For example, if the first and second anesthetic depths D_{RR}, D_{SYS} are extremely different from each other, the anesthetic depth determining means **62** judges, based on respective time-wise changes of the two anesthetic depths, which one of the two anesthetic depths D_{RR} and D_{SYS} is abnormal, and determines, as the third anesthetic depth D, the other of the anesthetic depths D_{RR} and D_{SYS}, or calculates respective weighing factors based on the respective time-wise changes of the two anesthetic depths and determines, as the third anesthetic depth D, an average value of the respective weighed values of the anesthetic depths D_{RR} and D_{SYS}. Meanwhile, if the first and second anesthetic depths D_{RR}, D_{SYS} are not so different from each other, the anesthetic depth determining means **62** determines, as the third anesthetic depth D, one of the two anesthetic depths D_{RR}, D_{SYS}, or an average value of the two anesthetic depths D_{RR} and D_{SYS}.

FIG. **7** is a flow chart representing the operation of the control device **16**, which shows a routine carried out in synchronism with a pulse or an input of a blood pressure value.

In FIG. **7**, at Step SA1 corresponding to the pulse period measuring means **50**, a pulse period T_{RR} is calculated as a time interval between respective R-waves of successive two pulses of the electrocardiographic waveform input from the electrocardiographic waveform detecting device **10**. Step SA1 is followed by Step SA2, corresponding to the pulse period fluctuation signal extracting means **52**, to perform a frequency analysis of a fluctuation of the pulse periods T_{RR} with a fast Fourier transformation (FFT) method, an autoregression (AR) method, or the like, and extract, as first and second pulse period fluctuation signals HFC_{RR}, LFC_{RR}, a magnitude (power) of a signal component having a peak frequency in a frequency range including a frequency (e.g., 0.25 Hz) of a respiration of the subject and a magnitude (power) of a signal component having a peak frequency in a frequency range including a frequency (e.g., 0.07 Hz) of about one third to one fourth of the frequency of the respiration of the subject, respectively.

Step SA2 is followed by Step SA3, corresponding to the first anesthetic calculating means **54**, to calculate a first anesthetic depth D_{RR} of the subject based on a ratio (LFC_{RR}/HFC_{RR}) of the first pulse period fluctuation signal HFC_{RR} to the second pulse period fluctuation signal LFC_{RR} according to the pre-stored relationship shown in FIG. **5**, for example.

Next, the control of the CPU **18** goes to Step SA4. At Step SA4, a blood pressure value P_{SYS} input from the blood pressure measuring device **20** is read in. Step SA4 is followed by Step SA5, corresponding to the blood pressure fluctuation signal extracting means **58**, to perform a frequency analysis of a fluctuation of the blood pressure values P_{SYS}, with a fast Fourier transformation (FFT) method, an autoregression (AR) method, or the like, and extract, as the blood pressure fluctuation signal LFC_{SYS}, a magnitude (power) of a signal component having a peak frequency in a frequency range including a frequency (e.g., 0.07 Hz) of about one third to one fourth of the frequency of the respiration of the subject.

Step SA5 is followed by Step SA6, corresponding to the second anesthetic depth calculating means **60**, to calculate a second anesthetic depth D_{SYS} of the subject based on the blood pressure fluctuation signal LFC_{SYS} extracted at Step SA5 according to the pre-stored relationship shown in FIG. **6**, for example.

Subsequently, the control of the CPU **18** goes to Step SA7, corresponding to the anesthetic depth determining means **62**, to determine a third anesthetic depth D having a higher reliability, based on the first anesthetic depth D_{RR} calculated on the basis of the fluctuation of pulse periods and the second anesthetic depth D_{SYS} calculated on the basis of the fluctuation of blood pressure values. For example, if the first and second anesthetic depths D_{RR}, D_{SYS} are extremely different from each other, one of the first and second anesthetic depths D_{RR}, D_{SYS} is judged as an abnormal value, based on respective time-wise changes of the two anesthetic depths, and the other of the first and second anesthetic depths D_{RR}, D_{SYS} is determined as the third anesthetic depth D. If the first and second anesthetic depths D_{RR}, D_{SYS} are not so different from each other, an average value of the first and second anesthetic depths D_{RR}, D_{SYS} is determined as the third anesthetic depth D. Step SA7 is followed by Step SA8 to quantitatively display, on the display device **30**, the anesthetic depth D determined at Step SA7, in digits, a trend graph, or the like. For instance, the anesthetic depth D is expressed with numerals by dividing the axis of abscissas of FIG. **5** or **6** into predetermined units.

In the above described embodiment, from the fluctuation of the pulse periods continuously measured at Step SA1 corresponding to the pulse period measuring means **50**, the first pulse period fluctuation signal HFC_{RR} which corresponds to the first pulse period fluctuation component produced in substantial synchronism with the respiration of the subject and the second pulse period fluctuation signal LFC_{RR} which corresponds to the second pulse period fluctuation component having the predetermined frequency lower than the frequency of the first pulse period fluctuation component are extracted at Step SA2 corresponding to the pulse period fluctuation signal extracting means **52**. Then, the first anesthetic depth D_{RR} of the subject is calculated at Step SA3 corresponding to the first anesthetic depth calculating means **54**, based on the ratio (LFC_{RR}/HFC_{RR}) of the first pulse period fluctuation signal HFC_{RR} to the second pulse period

fluctuation signal LFC_{RR}. Thus, the present apparatus can objectively or quantitatively calculate the first anesthetic depth D_{RR} of the subject and accurately obtain the anesthetic depth D_{RR} without needing operator's skill or the like.

In the present embodiment, the blood pressure values P_{SYS} of the subject are continuously measured by the blood pressure measuring means **56**. From the fluctuation of the continuously measured blood pressure values P_{SYS}, the blood pressure fluctuation signal LFC_{SYS} which corresponds to the blood pressure fluctuation component having the predetermined frequency lower than the frequency of the respiration of the subject is extracted at Step SA5 corresponding to the blood pressure fluctuation signal extracting means **58**. Then, the second anesthetic depth D_{SYS} of the subject is calculated at Step SA6 corresponding to the second anesthetic depth calculating means **60**, based on the magnitude of the blood pressure fluctuation signal LFC_{SYS}. Thus, the present apparatus can objectively or quantitatively calculate the second anesthetic depth D_{SYS} of the subject and accurately obtain the anesthetic depth D_{SYS} without needing operator's skill or the like.

In the present embodiment, based on the first anesthetic depth D_{RR} calculated on the basis of the fluctuation of pulse periods T_{RR} and the second anesthetic depth D_{SYS} on the basis of the fluctuation of blood pressure values P_{SYS}, the third anesthetic depth D having a higher reliability is determined at Step SA7 corresponding to the anesthetic depth determining means **62**, whereby the anesthetic depth D quantitatively displayed on the display device **30** enjoys the higher reliability.

Next, there will be described another embodiment according to the present invention. Hereinafter, the same parts as those of the prior embodiment are denoted by the same reference numerals and the detail description thereof is omitted.

FIG. **8** is a block diagram for explaining various functions of the control device **16** of an anesthetic depth measuring apparatus as another embodiment according to the present invention. In the figure, a change rate calculating means **64** calculates a rate of change, $\Delta T_{RR}/\Delta P_{SYS}$, of a pulse period T_{RR} to a blood pressure value P_{SYS}, based on the blood pressure values, for example, systolic blood pressure values P_{SYS} continuously measured by the blood pressure measuring means **56** and the pulse periods T_{RR} measured by the pulse period measuring means **50**, within a predetermined unit time which corresponds to, for example, ten pulses to several tens of pulses. For example, the rate of change $\Delta T_{RR}/\Delta P_{SYS}$ is calculated as a slope or inclination of a regression line determined on data points indicating actual blood pressure values P_{SYS} and actual pulse periods T_{RR} of the subject in a two-dimensional coordinate system defined by a first axis indicative of blood pressure values P_{SYS} and a second axis indicative of pulse periods T_{RR}.

When each data point indicative of an actual blood pressure value P_{SYS} and an actual pulse period T_{RR} of the anesthetized subject is plotted in the two-dimensional coordinate system defined by the first axis indicative of blood pressure values P_{SYS} and the second axis indicative of pulse periods T_{RR}, eventually those data points are located along a straight line. Thus, the blood pressure values and the pulse periods are related to each other. The rate of change $\Delta T_{RR}/\Delta P_{SYS}$ indicates the inclination of the straight line. When the subject is not anesthetized, the inclination of the straight line indicates a large value as shown in FIG. **9**, for example. When the subject is anesthetized, the inclination of the straight line indicates a small value as shown in FIG. **10**, for example. As one of nerve-based circulation control mechanisms, there is known a baroreceptor reflex which acts via an automatic nerve. The baroreceptor reflex causes an effector organ such as the heart, peripheral blood vessels, or the like to adjust heart rate or arterial pressure so as to eliminate changes of the blood pressure and keep the blood pressure constant. Further, the baroreceptor reflex not only reacts to changes of blood vessels due to a physiological stress, a postural change or a bleeding, but also is influenced by an anesthetic agent. Therefore, the rate of change $\Delta T_{RR}/\Delta P_{SYS}$ changes according to the anesthetic depth. A relationship shown in FIG. **11** is experimentally obtained in advance, based on the above described facts.

An anesthetic depth determining means **66** determines an anesthetic depth D of the subject based on the rate of change $\Delta T_{RR}/\Delta P_{SYS}$ calculated by the change rate calculating means **64** according to the pre-stored relationship shown in FIG. **11**.

FIG. **12** is a flow chart representing the operation of the control device **16** of the second apparatus, which shows a routine carried out in synchronism with a pulse or an input of a blood pressure value, or at a predetermined regular time interval or a predetermined unit of pulses.

In FIG. **12**, at Step SB1 corresponding to the pulse period measuring means **50**, a pulse period T_{RR} is calculated as a time interval between respective R-waves of successive two pulses of the electrocardiographic waveform input from the electrocardiographic waveform detecting device **10**. Step SB1 is followed by Step SB2 to read in, for example, a systolic blood pressure value P_{SYS} measured by the blood pressure measuring device **20** corresponding to the blood pressure measuring means **56**.

Step SB2 is followed by Step SB3, corresponding to the change rate calculating means **64**, to calculate a rate of change $\Delta T_{RR}/\Delta P_{SYS}$ as an inclination of a regression line obtained from a plurality of data points each indicating an actual blood pressure value P_{SYS} and an actual pulse period T_{RR} of the subject that are plotted in a two-dimensional coordinate system defined by a first axis indicative of blood pressure values P_{SYS} and a second axis indicative of pulse periods T_{RR}.

Subsequently, the control of the CPU **18** goes to Step SB4, corresponding to the anesthetic depth determining means **66**, to determine an anesthetic depth D of the subject based on the rate of change $\Delta T_{RR}/\Delta P_{SYS}$ calculated at Step SB3 according to the pre-stored relationship shown in FIG. **11**, for example. Step SB4 is followed by Step SB5 to display, on the display device **30**, the determined anesthetic depth D in digits, a trend graph, or the like.

In the above mentioned embodiment, the rate of change $\Delta T_{RR}/\Delta P_{SYS}$ is calculated at Step SB3 corresponding to the change rate calculating means **64**, based on the pulse periods T_{RR} continuously measured at Step SB1 corresponding to the pulse period measuring means **50** and the blood pressure values P_{SYS} continuously measured by the blood pressure measuring means **56**. Then, the anesthetic depth D is determined at Step SB4 corresponding to the anesthetic depth determining means **66**, based on the rate of change $\Delta T_{RR}/\Delta P_{SYS}$ according to the relationship shown in FIG. **11**. Thus, the second apparatus can objectively and quantitatively determine the anesthetic depth D of the subject and accurately obtain the anesthetic depth D without needing operator's skill or the like.

FIG. **13** is a diagrammatic view for illustrating the construction of an anesthetic depth measuring apparatus as yet another embodiment according to the present invention. In the figure, a peripheral body temperature measuring device

110 includes a peripheral body temperature measuring probe 112 which is worn on a living subject. The peripheral body temperature measuring device 110 measures a peripheral body temperature of the subject who is generally anesthetized by an inhalation anesthetic, such as isoflurane, and successively supplies a peripheral body temperature signal representative of the measured peripheral body temperature to a CPU 118 of a control device 116 via an A/D converter 114. The peripheral body temperature measuring probe 112 includes a thermistor, for example, and is adhered to a skin of the subject, such as a forehead or a sole.

A deep body temperature measuring device 120 includes a deep body temperature measuring probe 122 which is worn on the subject. The deep body temperature measuring device 120 measures a deep body temperature, that is, a central body temperature of the generally anesthetized subject, and successively supplies a deep body temperature signal representative of the measured deep body temperature to the CPU 118 via an A/D converter 124. The deep body temperature measuring probe 122 is constructed such that a temperature sensor portion thereof is insulated by a thermal insulator so that the sensor portion is brought into equilibrium with the deep body temperature of the subject. Otherwise, the deep body temperature measuring probe 122 may be provided by an insertion-type probe which is inserted into a rectum or an esophagus and measures a deep body temperature of a living the subject.

The control device 116 is provided by a so-called microcomputer including the CPU 118, a ROM 126 and a RAM 128. The CPU 118 processes input signals, that is, the peripheral body temperature signal and the deep body temperature signal, according to control programs pre-stored in the ROM 126 by utilizing a temporary-storage function of the RAM 128, and controls a display device 130 to display an anesthetic depth D of the subject.

FIG. 14 is a block diagram for explaining various functions of the control device 116. In the figure, a peripheral body temperature measuring means 150 corresponds to the peripheral body temperature measuring device 110 and measures a peripheral body temperature on a body surface of the subject. A deep body temperature measuring means 152 corresponds to the deep body temperature measuring device 120 and measures a deep body temperature in a central (deep) portion of the subject.

A temperature difference calculating means 154 calculates a difference S ($=T_{cent}-T_{dist}$) between the peripheral body temperature T_{dist} measured by the peripheral body temperature measuring means 150 and the deep body temperature T_{cent} measured by the deep body temperature measuring means 152. An anesthetic depth determining means 156 determines an anesthetic depth D_S based on the actual difference S according to a pre-stored relationship shown in FIG. 15, for example.

Meanwhile, a temperature ratio calculating means 158 calculates a ratio R (T_{cent}/T_{dist}) of the peripheral body temperature T_{dist} measured by the peripheral body temperature measuring means 150 to the deep body temperature T_{cent} measured by the deep body temperature measuring means 152. The anesthetic depth determining means 156 determines an anesthetic depth D_R based on the actual ratio R according to a pre-stored relationship shown in FIG. 16, for example. Further, the anesthetic depth determining means 156 determines a more reliable anesthetic depth D from the anesthetic depth D_S determined based on the difference S and the anesthetic depth D_R determined based on the ratio R.

Generally, blood vessels of an anesthetized patient tend to be relaxed and dilated. In this case, blood circulation of subject's peripheral portion is promoted and the peripheral body temperature T_{dist} is raised. Therefore, as the difference S ($=T_{cent}-T_{dist}$) between the peripheral body temperature T_{dist} and the deep body temperature (central temperature) T_{cent} or the ratio R ($=T_{cent}/T_{dist}$) of the central body temperature T_{cent} to the peripheral body temperature T_{dist} decreases, an anesthetic effect increases and the anesthetic depth D increases. The relationships shown in FIGS. 15 and 16 are experimentally obtained in advance, based on the above described facts.

FIG. 17 is a flow chart representing the operation of the control device 116, which shows a routine carried out in synchronism with an input of a peripheral or a deep body temperature T_{dist}, T_{cent}.

In FIG. 17, at Step SC1, a peripheral body temperature T_{dist} measured by the peripheral body temperature measuring device 110 is read in. Step SC1 is followed by Step SC2 to read in a deep body temperature T_{cent} measured by the deep body temperature measuring device 120. Step SC2 is followed by Step SC3, corresponding to the temperature difference calculating means 154, to calculate a difference S ($=T_{cent}-T_{dist}$) between the deep body temperature T_{cent} and the peripheral body temperature T_{dist}. Step SC3 is followed by Step SC4, corresponding to the anesthetic depth determining means 156, to determine an anesthetic depth D_S based on the actual difference S ($=T_{cent}-T_{dist}$) according to the pre-stored relationship shown in FIG. 15.

Subsequently, the control of the CPU 118 goes to Step SC5, corresponding to the temperature ratio calculating means 158. At Step SC5, a ratio R ($=T_{cent}/T_{dist}$) of the central body temperature T_{cent} to the peripheral body temperature T_{dist} is calculated. Step SC5 is followed by Step SC6, corresponding to the anesthetic depth determining means 156, to determine an anesthetic depth D_R based on the actual ratio R ($=T_{cent}/T_{dist}$) according to the pre-stored relationship shown in FIG. 16.

Step SC6 is followed by Step SC7, corresponding to the anesthetic depth determining means 156, to determine a more reliable anesthetic depth D based on the anesthetic depths D_S and D_R determined on the basis of the difference S ($=T_{cent}-T_{dist}$) and the ratio R ($=T_{cent}/T_{dist}$), respectively. For example, if the two anesthetic depths D_S and D_R are extremely different from each other, one of the two anesthetic depths is judged as an abnormal value, based on respective time-wise changes of the two anesthetic depth, and the other of the two anesthetic depths is determined as the anesthetic depth D. If the two anesthetic depths D_S and D_R are not so different from each other, an average value of the two anesthetic depths is determined as the anesthetic depth D.

Step SC7 is followed by Step SC8 to quantitatively display, on the display device 130, the anesthetic depth D determined at Step SC7 in digits, a trend graph, or the like. For instance, the anesthetic depth D is expressed with numerals by dividing the axis of abscissas of FIG. 15 or 16 into predetermined units.

In the above mentioned embodiment, at Step SC3 corresponding to the temperature difference calculating means 154, the difference S ($=T_{cent}-T_{dist}$) between the deep body temperature T_{cent} measured by the deep body temperature measuring means 152 and the peripheral body temperature T_{dist} measured by the peripheral body temperature measuring means 150 is calculated. At Step SC4 corresponding to the anesthetic depth determining means 156, the anesthetic

depth D_S of the subject is determined on the basis of the difference S ($=T_{cent}-T_{dist}$). Thus, the present apparatus can to objectively or quantitatively determine the anesthetic depth D_S of the subject and accurately obtain the anesthetic depth D_S without needing operator's skill or the like.

Further, in the present embodiment, at Step SC5 corresponding to the temperature ratio calculating means **158**, the ratio R ($=T_{cent}/T_{dist}$) of the central body temperature T_{cent} measured by the deep body temperature measuring means **152** to the peripheral body temperature T_{dist} measured by the peripheral body temperature measuring means **150** is calculated. At Step SC6 corresponding to the anesthetic depth determining means **156**, the anesthetic depth D_R of the subject is determined on the basis of the ratio R ($=T_{cent}/T_{dist}$) calculated by the temperature ratio calculating means **158**. Thus, the present apparatus can objectively or quantitatively determine the anesthetic depth D_S of the subject and accurately obtain the anesthetic depth D_S without needing operator's skill or the like.

In the present embodiment, at Step SC7 corresponding to the anesthetic depth determining means **156**, the anesthetic depth D having a higher reliability is determined, based on the anesthetic depth D_S determined on the basis of the temperature difference S ($=T_{cent}-T_{dist}$) and the anesthetic depth D_R determined on the basis of the temperature ratio R ($=T_{cent}/T_{dist}$), whereby the anesthetic depth D quantitatively displayed on the display device **130** enjoys the high reliability.

While the present invention has been described in its preferred embodiments by reference to the drawings, it is to be understood that the invention may otherwise be embodied.

In the embodiment shown in FIG. **2**, both the means **50**, **52**, **54** for calculating the first anesthetic depth D_{RR} from the fluctuation of the pulse periods T_{RR}, and the means **56**, **58**, **60** for calculating the second anesthetic depth D_{SYS} from the fluctuation of the blood pressure values P_{SYS} are employed. However, even if one of the two means for calculating the first and second anesthetic depths D_{RR}, D_{SYS} is omitted, the apparatus can have the function of measuring an anesthetic depth.

Moreover, in the embodiment of FIG. **2**, the pulse period T_{RR} of the subject is continuously measured by calculating a period of an electrocardiographic waveform (ECG) detected by the electrocardiographic waveform detecting device **10**, for example, calculating a time interval between respective R-waves of each pair of successive two pulses of the electrocardiographic waveform. However, it is possible to employ a means for pulse-synchronously calculating a period of a pulse wave detected by a well-known cuff or pressure pulse wave sensor from an artery of a living subject, or a means for pulse-synchronously calculating a period of a volume pulse wave detected by a photoelectric pulse wave sensor. In short, any kind of means for continuously measuring a pulse period of the subject may be provided. For example, when a pulse period is measured on the basis of the pressure pulse wave detected by the pressure pulse wave detecting probe **22** of the blood pressure measuring device **20**, the electrocardiographic detecting device **10** is not needed.

In the embodiment shown in FIG. **2**, as the pulse period T_{RR}, the blood pressure value P_{SYS}, or the anesthetic depth D_{RR} or D_{SYS}, a moving average of values pulse-synchronously obtained within a predetermined period may be used. Further, the pulse period T_{RR} or the blood pressure value P_{SYS} may be obtained based on every second or third pulse.

In the embodiment shown in FIG. **2**, the pulse period fluctuation signal extracting means **52** or the blood pressure fluctuation signal extracting means **58** may be provided by a digital filter for discriminating a micro-oscillation signal having a low frequency.

In the embodiment shown in FIG. **2**, for the anesthetic depth D_{SYS} calculation, the fluctuation of the systolic blood pressure values P_{SYS} measured by the blood pressure measuring means **56** are used. However, a fluctuation of mean blood pressure values P_{MEAN} or diastolic blood pressure values P_{DIA} measured by the blood pressure measuring means **56** may be used.

In the embodiment shown in FIG. **2**, the first and second pulse period fluctuation signals HFC_{RR}, LFC_{RR} are obtained from the pulse periods T_{RR} continuously measured by the pulse period measuring means **50**. However, since the pulse period T_{RR} (sec.) corresponds to a pulse rate PR ($=60/T_{RR}$), one to one, a means for measuring a pulse rate PR may be employed in place of the pulse period measuring means **50**, and, from a fluctuation of the pulse rates PR, a first pulse rate fluctuation signal corresponding to a respiratory fluctuation and a second pulse rate fluctuation signal corresponding to one third to one fourth of the respiratory fluctuation may obtained.

In the embodiment shown in FIG. **2**, the first anesthetic depth D_{RR} of the subject is calculated on the basis of the ratio (LFC_{RR}/HFC_{RR}) of the second pulse period fluctuation signal LFC_{RR} to the first pulse period fluctuation signal HFC_{RR} and the second anesthetic depth D_{SYS} is calculated on the basis of the magnitude of the blood pressure fluctuation signal LFC_{SYS}. However, the ratio (LFC_{RR}/HFC_{RR}) or the blood pressure fluctuation signal LFC_{SYS} may be corrected or modified based on other parameters. In any case, the first anesthetic depth D_{RR} of the subject is calculated on the basis of the ratio (LFC_{RR}/HFC_{RR}) of the second pulse period fluctuation signal LFC_{RR} to the first pulse period fluctuation signal HFC_{RR} and the second anesthetic depth D_{SYS} is calculated on the basis of the magnitude of the blood pressure fluctuation signal LFC_{SYS}.

In the embodiment shown in FIG. **8**, the rate of change $\Delta T_{RR}/\Delta P_{SYS}$ of the pulse period T_{RR} to the blood pressure value P_{SYS} is calculated and the anesthetic depth D is calculated on the basis of the rate of change $\Delta T_{RR}/\Delta P_{SYS}$. However, a rate of change $\Delta P_{SYS}/\Delta T_{RR}$ of the blood pressure value P_{SYS} to the pulse period T_{RR} may be used. The rate of change $\Delta P_{SYS}/\Delta T_{RR}$ increases with increasing of the anesthetic depth D.

In the embodiment shown in FIG. **8**, the pulse period T_{RR} is used. However, a heart rate HR may be used. Since the pulse period T_{RR} is the inverse of the heart rate HR, a rate of change of the heart rate HR to the blood pressure value P_{SYS} can be regarded as substantially the same as the rate of change $\Delta T_{RR}/\Delta P_{SYS}$.

In the embodiment shown in FIG. **8**, the pulse period T_{RR} and the blood pressure value P_{SYS} are measured corresponding to each one pulse. However, the pulse period T_{RR} and the blood pressure value P_{SYS} may be measured at a predetermined regular interval which corresponds to two or more pulses. In addition, the pulse period T_{RR} and the blood pressure value P_{SYS} may be measured during an operation period which is started and ended at a predetermined cycle.

In the embodiment shown in FIG. **8**, the pulse period T_{RR} of the subject is continuously measured by calculating a period of an electrocardiographic waveform (ECG) detected by the electrocardiographic waveform detecting device **10**, for example, calculating a time interval between respective

R-waves of each pair of successive two pulses of the electrocardiographic waveform. However, it is possible to employ a means for pulse-synchronously calculating a period of a pulse wave detected by a well-known cuff or pressure pulse wave sensor from an artery of a living subject, or a means for pulse-synchronously calculating a period of a volume pulse wave detected by a photoelectric pulse wave sensor. In short, any kind of means for continuously measuring a pulse period of the subject may be provided. For example, when a pulse period is measured on the basis of the pressure pulse wave detected by the pressure pulse wave detecting probe **22** of the blood pressure measuring device **20**, the electrocardiographic detecting device **10** is not needed.

In the embodiment shown in FIG. **8**, the systolic blood pressure values P_{SYS} measured by the blood pressure measuring device **20** are used. However, the mean blood pressure values P_{MEAN} or the diastolic blood pressure values P_{DIA} may be used.

In the embodiment shown in FIG. **8**, as the pulse period T_{RR} or the blood pressure value P_{SYS}, a moving average of values pulse-synchronously obtained within a predetermined duration may be used.

In the embodiment shown in FIG. **8**, the anesthetic depth D is determined on the basis of the rate of change $\Delta T_{RR}/\Delta P_{SYS}$. However, the rate of change $\Delta T_{RR}/\Delta P_{SYS}$ may be corrected or modified based on other parameters. In any case, the anesthetic depth D is determined on the basis of the rate of change $\Delta T_{RR}/\Delta P_{SYS}$.

In the embodiment shown in FIG. **13**, both the means **154** and Steps SC3 and SC4 for calculating the anesthetic depth D_S based on the temperature difference S ($=T_{cent}-T_{dist}$), and the means **158** and Steps SC5 and SC6 for calculating the anesthetic depth D_R based on the temperature ratio R ($=T_{cent}/T_{dist}$) are employed. However, one of the above-indicated two anesthetic depth determining devices may be omitted.

In the embodiment shown in FIG. **13**, the anesthetic depths D_S and D_R are calculated on the basis of the temperature difference S ($=T_{cent}-T_{dist}$) and the temperature ratio R ($=T_{cent}/T_{dist}$), respectively. However, the temperature difference S ($=T_{cent}-T_{dist}$) or the temperature ratio R ($=T_{cent}/T_{dist}$) may be corrected or modified based on other parameters. In any case, the anesthetic depth D_S or D_R is calculated on the basis of the temperature difference S ($=T_{cent}-T_{dist}$) or the temperature ratio R ($=T_{cent}/T_{dist}$), respectively.

It is to be understood that the present invention may be embodied with other changes and modifications that may occur to those skilled in the art without departing from the scope of the invention.

INDUSTRIAL UTILITY

It is understood from the above description that since the anesthetic depth measuring apparatuses according to the present invention can quantitatively and objectively measure an anesthetic depth of a patient, they are suitable for use in an operating room, an intensive care unit, or the like where the patient is generally anesthetized.

We claim:

1. An anesthetic depth measuring apparatus for measuring an anesthetic depth of a living subject, characterized by comprising:

a pulse period measuring device which continuously measures a period of a pulse of the subject;

pulse period fluctuation signal extracting means for extracting, from a fluctuation of the pulse periods continuously measured by said pulse period measuring device, a first pulse period fluctuation signal which corresponds to a first pulse period fluctuation component produced in substantial synchronism with a respiration of the subject and a second pulse period fluctuation signal which corresponds to a second pulse period fluctuation component having a predetermined frequency lower than a frequency of the first pulse period fluctuation component; and

anesthetic depth calculating means for calculating an anesthetic depth of the subject based on a ratio of said first pulse period fluctuation signal to said second pulse period fluctuation signal.

2. An anesthetic depth measuring apparatus according to claim **1**, wherein said pulse period fluctuation signal extracting means extracts, as said first pulse period fluctuation signal, pulse period fluctuation components having frequencies in a predetermined frequency range including a frequency of the respiration of the subject.

3. An anesthetic depth measuring apparatus according to claim **1**, wherein said pulse period fluctuation signal extracting means extracts, as said second pulse period fluctuation signal, pulse period fluctuation components having frequencies in a predetermined frequency range including a frequency of about one third to one fourth of a frequency of the respiration of the subject.

4. An anesthetic depth measuring apparatus for measuring an anesthetic depth of a living subject, characterized by comprising:

a pulse period measuring device which continuously measures a period of a pulse of the subject;

pulse period fluctuation signal extracting means for extracting, from a fluctuation of the pulse periods continuously measured by said pulse period measuring device, a first pulse period fluctuation signal which corresponds to a first pulse period fluctuation component produced in substantial synchronism with a respiration of the subject and a second pulse period fluctuation signal which corresponds to a second pulse period fluctuation component having a predetermined frequency lower than a frequency of the first pulse period fluctuation component;

first anesthetic depth calculating means for calculating a first anesthetic depth of the subject based on a ratio of said first pulse period fluctuation signal to said second pulse period fluctuation signal;

a blood pressure measuring device which continuously measures a blood pressure value of the subject;

blood pressure fluctuation signal extracting means for extracting, from a fluctuation of the blood pressure values continuously measured by said blood pressure measuring device, a blood pressure fluctuation signal which corresponds to a blood pressure fluctuation component having a predetermined frequency lower than a frequency of a respiration of the subject;

second anesthetic depth calculating means for calculating a second anesthetic depth of the subject based on a magnitude of said blood pressure fluctuation signal; and

anesthetic depth determining means for determining a third anesthetic depth of the subject based on the first anesthetic depth calculated by said first anesthetic depth calculating means and the second anesthetic depth calculated by said second anesthetic depth calculating means, so that the determined third anesthetic depth is displayed on a display device.

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